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Physical Origin of Current Collapse in Au-free AlGaN/GaN Schottky Barrier Diode

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Abstract

Dynamic characterization (Pulsed *I-V*) on Au-free AlGaN/GaN Schottky Barrier Diodes (SBDs) has been performed to evaluate the impact of a negative quiescent bias on the forward characteristic. Results show an increase of on-resistance when more negative quiescent biases are applied, and a sudden current collapse phenomenon when the quiescent bias exceeds -175 V. Furthermore, the measurements show a common signature: the total current collapse is the result of the trapping phenomena occurring around the Schottky contact corner. In this paper, a TCAD model with two discrete donor states has been defined, to aim in the understanding of the role of surface donor states and explaining the observed behavior of AlGaN/GaN SBDs from this dynamic measurement. We propose that trapping at deep energy levels, existing at the Si_3N_4/AlGaN interface, is responsible for the gradual current reduction observed for negative quiescent biases up to Anode-to-Cathode voltage (V_{AC}) of -175 V. The electron filling of the shallower traps with high density at energy level located 0.3 eV below the conduction band starts at higher reverse bias, resulting in a strong Fermi-level pinning, which can be the cause of sudden current collapse.

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1. Introduction

AlGaN/GaN Schottky Barrier Diodes (SBDs) have been fabricated on 200 mm GaN-on-Si wafers with Au-free CMOS-compatible process flow [1]. The dynamic stability of the device can be a practical issue due to trapping/de-trapping of the surface donor states which are commonly known to be a major source of electrons for the formation of two-dimensional electron gas (2DEG) [2].

In this paper, we investigate the role of surface donor states on the dynamic behavior of AlGaN/GaN SBDs in pulsed regime. With a simple model defined in the TCAD simulator, we are able to qualitatively explain the experimental observations.

2. Results and discussion

The schematic of the SBDs studied is shown in Fig. 1. The devices measured are single anode finger AlGaN/GaN SBDs.

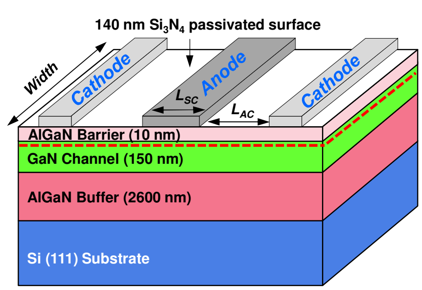

Fig. 1. Schematic of AlGaN/GaN-on-Si SBD with Anode-to-Cathode distance L_{AC} = 5 μm, Anode finger width = 100 μm, Schottky contact length L_{SC} = 9 μm.

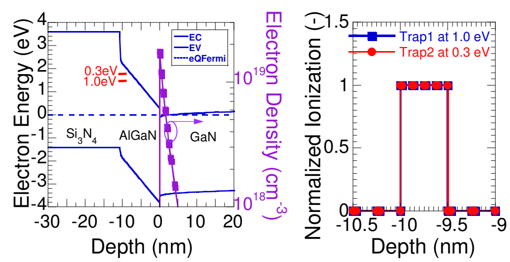

Fig. 2. (a) The simulated band diagram and 2DEG density at equilibrium, and (b) normalized ionization of the traps defined at the Si_3N_4/AlGaN interface.

The measurement procedure was developed by using an Agilent B1505A to measure the pulsed *I-V* characteristics. Each point of the forward *I-V* characteristic is preceded by a 10 ms stressing pulse (quiescent state) at a negative bias (V_R) which varies from 0 V to -200 V.

Donor-like trap levels have been defined in the TCAD simulation structure at the Si_3N_4/AlGaN interface. The densities of the donor traps are set as 1.25×10^{12} cm^{-2} and 2.25×10^{13} cm^{-2} at "Trap1" of 1.0 eV and "Trap2" of 0.3 eV, respectively [3, 4]. As shown in Fig. 2, the normalized ionization of the two traps defined is shown to be "1" at equilibrium, i.e. all the interface traps are ionized with positive charges.

In Fig. 3 (left), typical pulsed *I-V* characteristics with changing V_R for AlGaN/GaN SBD are shown. Two regimes have been observed in terms of current levels: gradual current reduction before a critical voltage and total current collapse when V_R goes beyond the critical voltage. The gradual current reduction is correlated with the increase of on-resistance shown in Fig. 3 (right). Moreover, the

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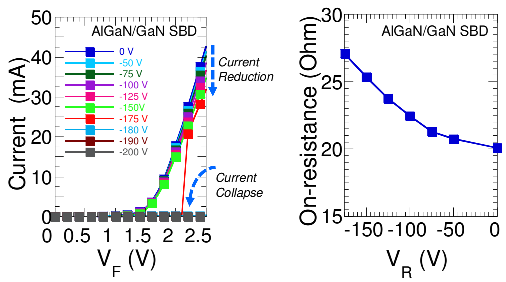

Fig. 3. Pulsed forward *I-V* characteristics with a variation of the stressing voltage V_R from 0 V to -200 V (left); The variation of on-resistance with changing V_R which correlates to the current reduction (right).

totally collapsed current can still abruptly jump to the "normal" level when a sufficiently high forward voltage triggers the de-pinning of the Fermi level.

At low voltage range of V_R, the electrons are first captured by "Trap1" as shown in Fig. 4 (left). The simulated band diagram at V_{AC} = -150 V is shown in Fig . 4 (right). The quasi-Fermi level is pinned at the "Trap1" energy level with electrons charging those deeper trap states. The "Trap2" remains ionized. With increasing reverse bias, this trap region extends laterally (shown in Fig. 5). This lateral extension partially depletes the 2DEG under this region, explaining the observation of on-resistance increase in Fig. 3 (right)

At even more negative bias, "Trap2" starts to be filled with injected electrons due to the further bending of the energy band laterally. The simulated band diagram (at V_{AC} = -175 V) in Fig. 6 (left) shows that the quasi-Fermi level is pinned at the trap level of 0.3 eV. The normalized ionization from simulation shown in Fig. 6 (right) confirms the process of electron-filling at "Trap2". The process of electron-

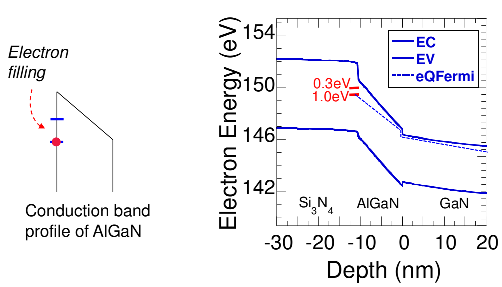

Fig. 4. The conduction band profile of AlGaN barrier layer under reserve biased condition when the injected electron is captured by a deep trap level (left); The simulated band diagram at V_{AC} = -150 V (right).

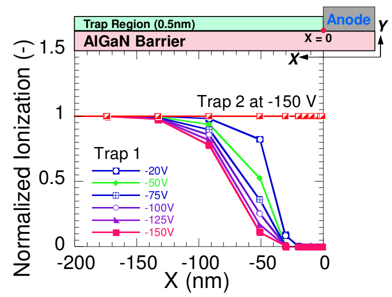

Fig. 5. The lateral distribution of normalized ionization for "Trap1" with different V_R down to -150 V and for "Trap2" at V_R = -150 V. The position of X = 0 nm corresponds to the corner of Schottky contact.

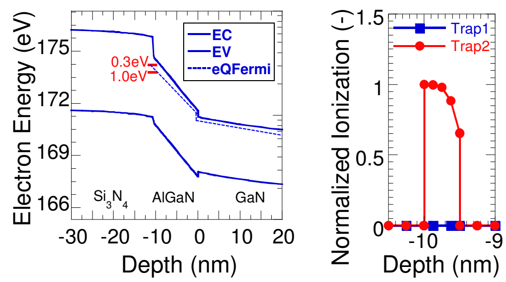

Fig. 6. The simulated band diagram at V_{AC} = -175 V for SBD (right), the normalized ionization of "Trap1" and "Trap2" at V_{AC} = -175 V.

filling at "Trap2", can fully deplete the underlying 2DEG, due to the large trap density at this energy level. This leads to a blocking of the current in the forward regime, which is sustained until the traps are re-ionized at sufficiently high forward bias, at which moment a de-pinning of the Fermi-level occurs.

3. Conclusions

This work shows the pulsed *I-V* measurements on Au-free AlGaN/GaN SBDs and then correlates the trapping phenomena of surface donor states with the experimental results. A simple model was created in a TCAD simulator, which aided in the understanding and explanation of the observations.

References

[1] S. Lenci, ***et al.***, *IEEE Electron Device Lett.*, **34***,* 8*,* pp. 1035–1037, Aug. 2013.

[2] J. B. Ibbetson, ***et al.***, *Appl. Phys. Lett.*,**77**, 2, pp. 250–252, Jul. 2000.

[3] Y. Shu, ***et al.***, submission to *IEEE Electron Device Lett.*.

[4] M. Gassoumi, ***et al.***, *Semiconductors,***46**, 3, 2012.